Problem 1 (20 points)

Please answer the following questions:

(a) A fully developed turbulent flow in a pipe can be roughly divided into three regions. Please give their names in the order from the wall to the center of the pipe. (3 points)

(b) Draw the plot of Fanning fraction factor versus Re for a pipe flow. Please remark the important features in the plot. (5 points)

(c) Please show the "Reynolds Analogy" and briefly explain how to apply this "Reynolds Analogy"? (4 points)

(d) Please define "Thermally fully developed condition" and explain why the convective heat transfer coefficient, h, remains constant in the "thermally fully developed region". (5 points)

(e) Please briefly explain the "Wien's Displacement Law". (3 points)

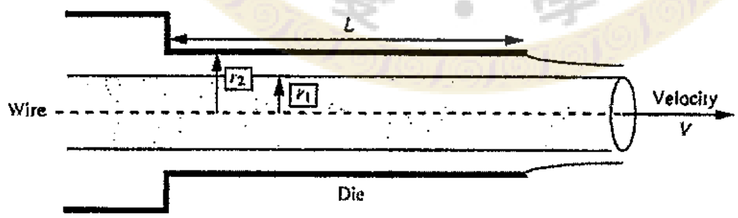
Problem 2 (20 points)

The following figure illustrates a wire coating process. The rod-like wire of radius r_1 is being steadily pulled with velocity V through a horizontal die of length L and internal radius r_2. The wire and the die are coaxial, and the space between them is filled with an incompressible liquid with constant viscosity μ. The pressure at both ends of the die is atmospheric. You can assume $v_r=v_\theta=0$ and $v_z=v_z(r)$ only. Also, the flow is assumed to be hydrodynamically fully-developed.

(a) Use **shell balances** to construct the governing equation. (4 points) Please indicate the physical meaning of each term (6 points)

(b) Determine v_z within the annular space. (5 points)

(c) Determine the force needed to pull the wire. (5 points)



Problem 3 (20 points)

Solute A is to be extracted from a feed mixture of 30 wt% A and 70 wt% solvent (C) by a second solvent (S) using a counter-current multiple contact extraction unit. The phase diagram is given in the following figure. The final raffinate is to contain 5 wt% A on a S-free basis. (a) Determine the weight fraction of A in the final extraction and the number of equilibrium stages required if the mass ratio of solvent-to-feed ratio is

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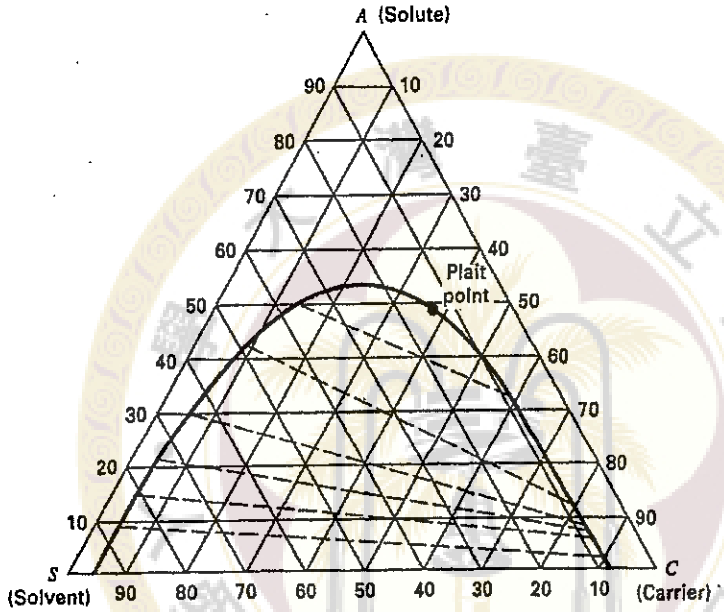
1/3. (10 points) (b) There exists a maximum value for the solvent-to-feed ratio. At this ratio, only the extraction but no reffinate will be obtained. Determine this ratio. (5 points) (c) In this system, sometimes a bad choice of the solvent-to-feed ratio causes a situation that an infinite number of stages are required to reach the desired results. At which condition will this situation occur? (5 points).



Problem 4 (20 points)

You are given a concentric tube (double pipe) heat exchanger with an area of 50m^2 operating under the following conditions:

Description	Heat capacity rate C_p, kW/K	Inlet temperature t_i, °C	Outlet temperature t_o, °C
Hot fluid	6	70	—
Cold fluid	3	30	60

1. What would be the outlet temperature of hot fluid? (4 points)
2. Is this heat exchanger operating in counter flow or parallel flow or cannot be determined from the information provided above? (4 points)
3. Please determine the overall heat-transfer coefficient. (4 points)
4. Please define and calculate the effectiveness of this heat exchanger. (4 points)
5. What would be the effectiveness of this heat exchanger if its length were greatly increased? (4 points)

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Problem 5 (20 points)

Consider a spherical organism of radius R within which respiration occurs at a uniform volumetric rate of $r_A = -k_1C_A$ (i.e., The consumption of oxygen (species A) is governed by a first-order, homogeneous chemical reaction). A molar concentration of $C_A(R) = C_{A,0}$ is maintained at the surface of the organism.

(a) Use "shell balances" to construct the governing equation and list the appropriate boundary conditions for the given system. (6 points)

(b) Please obtain an expression for the radial distribution of oxygen, $C_A(r)$, within the organism. (5 points)

(c) Please obtain an expression for the rate of oxygen consumption within the organism. (5 points)

(d) Consider an organism of radius R = 0.10 mm and a diffusion coefficient for oxygen transfer of $D_{AB} = 10^{-8}\ m^2/s$. If $C_{A,0} = 5\times10^{-5}\ kmol/m^3$ and $k_1 = 20\ s^{-1}$, what is the molar concentration of oxygen at the center of the organism? What is the rate of oxygen consumption by the organism? (4 points)